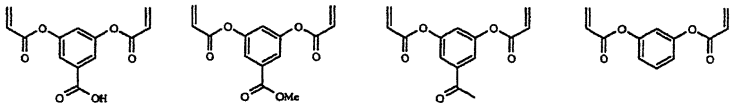
Synopsis

This thesis presents investigations carried out in two distinct areas The first part deals with the development of highly functionalized crosslinked matrices, while the latter deals with the study of new types of surfactants, namely counter-ion crosslinkable/polymerizable surfactants.

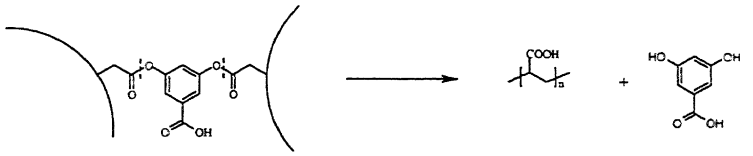
Degradable matrices have been extensively used in a variety of biomedical applications, such as absorbable sutures, sustained and targeted drug delivery, etc In most of these applications, the rate of degradation needs to be carefully modulated to suit a specific application Crosslinked degradable matrices form a unique class of materials, which have potential for use in controlled release systems Crosslinked networks generally have mechanical properties that are superior to the corresponding linear polymers, making them useful for a wider variety of applications. In the part A of the thesis (**chapter 2**), we discuss the concept and synthesis of a novel functional crosslinker – 3,5-diacryloyloxy benzoic acid (**DABA**) as shown in scheme 1



Scheme 1 Structures of the crosslinkers

This crosslinker is unique as it contains a carboxylic acid functionality in addition to two polymerizable acrylate groups Free radical polymerization of this crosslinker resulted in a highly crosslinked matrix possessing a very high density of carboxylic groups. This matrix underwent facile *hydrolytic decrosslinking* when subjected to aqueous alkali but was stable under acidic and neutral conditions. Such matrices that degrade only under certain pH conditions could be potentially useful for certain biomedical applications. With a view to gain a better understanding of this process, the kinetics of this decrosslinking (as shown in scheme 2) was studied by following the concentration of the degradation product, 3,5-dihydroxy benzoic acid using UV-visible spectroscopy. ^{1}H NMR investigations in NaOD/D_2O were also carried out to confirm that this decrosslinking process is indeed hydrolytic and

that it leads to the formation of poly(acrylic acid) and 3,5-dihydroxy benzoic acid, as shown below



Scheme 2 Mechanism of de-crosslinking

The acid groups, in the crosslinked matrix, it was argued could impart a high level of hydrophilicity to the matrix, especially under alkaline conditions. In order to understand the role of the carboxylic acid groups in the degradation process, three structurally similar crosslinkers, that are devoid of the acid functionality, viz methyl 3,5-diacryloyloxy benzoate (**MDAB**), 3,5-diacryloyloxy acetophenone (**DAAP**) and 1,3-diacryloyloxy benzene (**DAB**) were synthesized as shown in Scheme1, and the degradation kinetics of the corresponding crosslinked matrices were investigated similarly using UV-vis and NMR spectroscopic studies. The degradation profiles of the polymers showing the time evolution of the normalized absorbances (which represent the concentration of the product) are overlaid in figure 1. It is apparent from these profiles that the acid-containing polymer matrix degraded at a significantly faster rate This suggested that the formation of ionic carboxylate groups on the particle surface leads to an enhanced rate of diffusion of hydroxide and water, thereby increasing rate of hydrolysis. This process was termed as "*reactive diffusion controlled rate enhancement*"

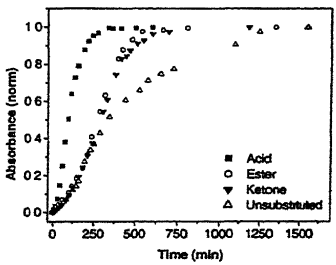


Figure 1 Comparison of the degradation profiles of the various polymer matrices

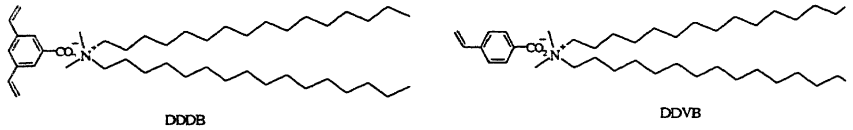
A simple statistical model, assuming a random scission of the two aryl ester linkages, permitted the retrieval of composite rate constants for the degradation of the various matrices These values were in concurrence with our suggestion of a *reactive diffusion-controlled rate enhancement* in the acid matrix

The second part (part B) of the work deals with *counter-ion polymerizable and crosslinkable surfactants* Self-organized surfactant phases have received a lot of attention as possible reaction and templating media Over the last 15 years, in an attempt to stabilize these phases, many polymerizable surfactants have been synthesized and a variety of surfactant aggregates have been stabilized by polymerization The main consideration in designing such surfactants lies in the choice and position of the reactive group, which affect the final structure and properties of the polymerized assembly. A majority of the surfactants contain polymerizable groups in the surfactant tail or head, while very few involve polymerization in the counter-ion Needless to add that the formation of crosslinks during polymerization further impacts the properties of these assemblies greatly.

Having developed a crosslinker, **DABA** containing a carboxylic acid, it became apparent that exchange of the anion, such as bromide in standard cationic surfactants like CTAB, should permit the generation of novel counter-ion crosslinkable surfactants. Such surfactants present unique opportunities to selectively locate the polymerizable unit at the hydrophilic/hydrophobic interface in a rich variety of aggregate structures that surfactants are known to form Polymerization and crosslinking at the counter-ion would be an example where the polymer chain would encase the aggregate by electrostatic interaction, while the hydrocarbon tails retain their monomeric state Our initial efforts were aimed at preparing such counterion-crosslinkable surfactant using DABA However, it was soon realized that inadvertent partial hydrolysis of the aryl ester linkages resulted in the formation of small amounts of surfactants devoid of polymerizable units. To overcome this problem, we designed and synthesized a new crosslinker, 3,5-divinyl benzoic acid (**DVBA**), which was devoid of the hydrolytically susceptible linkages. The strategy followed was to replace the bromide ion in micelle-forming cationic surfactants

cetyltrimethylammonium bromide (CTAB) and the vesicle forming dicetyldimethylammonium bromide (DDAB) with the crosslinkable divinyl benzoate Similarly, the analogous counter-ion polymerizable surfactants were prepared by exchanging the bromide with vinyl benzoate

In **chapter 3**, the crosslinking and polymerization of the vesicular aggregates are discussed Vesicles have received much attention, as they are the closest models to biological membranes This chapter presents the synthesis of dicetyldimethyl vinylbenzoate (DDVB) and dicetyldimethyl 3,5-divinylbenzoate (DDDB), whose structures are shown in scheme 3.



DDDB DDVB

Scheme 3 Structures of DDDB and DDVB

Both homo and mixed vesicles (with different amounts of crosslinker were prepared and characterized by TEM and zeta-sizer The kinetics of the photopolymerization of these amphiphiles using DMPA as the photoinitiator was studied by UV-visible spectroscopy Both the linearly polymerized and the crosslinked vesicles exhibited equally enhanced temporal stability, but there was a distinct difference in their stability with respect to surfactant lysis and ethanol tolerance experiments. The vesicle-to-mixed micelle transition (o lysis) can be induced by addition of single-tail surfactants to vesicular suspensions. Figure 2 shows the normalized scattered light intensity as a function of number of equivalents of CTAB added This experiment clearly shows that the unpolymerized and the linearly polymerized ones break down to generate smaller aggregate structures, such as mixed micelles while, the crosslinked ones exhibited enhanced stability with increasing extents of crosslinking Similarly, stability experiments performed in presence of an organic solvent, like ethanol, demonstrated the enhanced stability of the crosslinked vesicles compared to the linear ones.

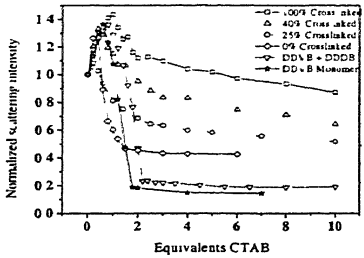
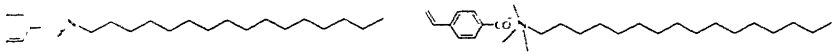


Figure 2 Light scattering intensity versus equivalents of CTAB for DDVB monomer (☆), 40% DDDB (▽), poly(DDVB) (◇), poly(25% DDDB) (○), poly(40% DDDB) (△), poly(DDDB) (□)

Unlike the two-tail surfactants, single-tail surfactants form a range of organizates, starting from simple spherical micelles to complex bicontinuous gyroid phases at high concentration. In order to explore the possibility of forming and freezing such assemblies, analogous single-tail surfactants with polymerizable (crosslinkable) counterions were prepared **Chapter 4** presents the synthesis of two such counter-ion polymerizable surfactants, CTVB and CTDVB, whose structures are shown in scheme 4. The characterization of the surfactants were done by XRD, polarizing optical microscope and conductivity. These organic counter-ion based surfactants had lower c m.c.'s compared to CTAB and formed highly viscoelastic worm-like micellar solutions, as was earlier seen in the case of cetyltrimethylammonium tosylate (CTAT), even without the addition of salt Both the crosslinking and polymerization of the micellar solutions (0.1 wt. %, above the c m c.) resulted in stable non-viscous solutions where the cylindrical structure of the parent micelle appears to be partially preserved. These polymerized aggregates were stable to dilution and did not exhibit any c.m c., confirming the micellar dynamics had been effectively arrested as a result of polymerization Kinetics of photopolymerization of these solutions monitored by UV-visible spectroscopy showed the conversion kinetics using DMPA, an oil-soluble initiator to be significantly faster compared to water-soluble initiator, CAVA



CTDVB CTVB

Scheme 4 Structures of CTDVB and CTVB

Variable temperature ^{1}H NMR studies were done to study the transformation of worm-like micelles to spherical micelles, whereas the polymerized aggregates were insensitive to temperature These surfactants provided the opportunity for templating/imprinting the hydrocarbon tails Preliminary studies on crosslinking of CTDVB at higher concentrations (20 wt %) and subsequent removal of the surfactant yielded highly functionalized, porous organic solid that is reminiscent of zeolites Conductometric titrations were done to differentiate between the accessibility of carboxyl groups in a simple imprinted divinylbenzoic acid (DVB) polymer and the above porous solid, as shown in figure 3 The flat region of the curve showed the accessibility to be 96% in case of the porous solid and only 36% in case of simple imprinted polymer.

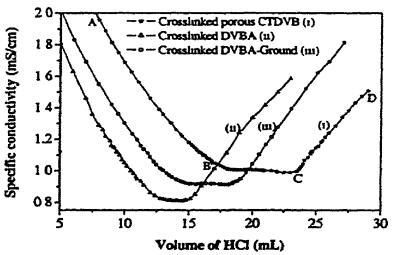
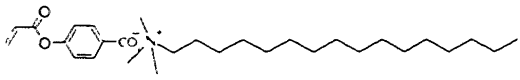


Figure 3 Conductometric titration curves for (i) templated porous CTDVB, (ii) crosslinked DVBA and (iii) crosslinked DVBA-ground

Chapter 5 presents studies to prepare carboxylate-functionalized poly(styrene) latexes by emulsion polymerization. In this case, the DABA-based counter-ion polymerizable surfactant cetyltrimethylammonium (4-acryloyloxybenzoate), CTAA based on acryloyloxy unit, was utilized as the emulsifier Emulsion polymerization was done in the conventional batch method with varying amounts of surfactant to obtain fairly monodisperse stable latexes.



CTAA

Scheme 5 Structure of CTAA

The incorporation of surfactant, which was nearly quantitative, was determined by UV-visible spectroscopy by hydrolysis of the labile acrylate ester bonds The hydrolyzed product gave rise to carboxylated poly(styrene) (copolymer of styrene and sodium acrylate) From the conductometric titration of the carboxylated poly(styrene) latexes, surface carboxyl groups were calculated